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THE COMPOSITION OF KULAITE

SEVERAL years ago I published[1] as an inaugural dissertation an account of the volcanoes of Kula, in Lydia, Asia Minor. In this the recent lavas of the region were described, to which rocks the name of "Kulaite" was given, the definition being, "a subgroup of the basalts which is characterized by the presence of hornblende as an essential constituent, which surpasses the augite in quantity and importance." The varieties of leucite-kulaite and nepheline-kulaite were also recognized, the essential character of all being the predominance of hornblende over augite.

Although the analysis made for me by Dr. Röhrig showed, for basalts, abnormally high Na_2O, yet little attention was paid to this feature and, attempts at identifying nepheline in the groundmass having failed, the kulaites were regarded essentially as plagioclase-basalts in which the pyroxene was largely replaced by hornblende.

In his latest book, Rosenbusch[2] recognizes this combination of high alkalis with a basic combination, and refers them to his group of trachydolerites, an intermediate group corresponding to the latities of Ransome,[3] which are effusive equivalents of the monzonites and intermediate between trachytes and andesites or basalts.

Study of other rocks of Asia Minor, which also showed similar latitic features, as well as the growing importance of these intermediate types, also called my attention again to the Kula rocks, and led to a reëxamination of them. This seemed especially needful chemically, since, as was pointed out to me by Professor Iddings, judging from the description published in 1894, there seemed to be no mineral present which would account for the high alkalis. In addition, for such basic rocks, Al_2O_3 seemed to be very high and MgO very low, and it was feared that Dr. Röhrig had made the common error of precipitating some MgO along with the Al_2O_3. I am happy to be able to say that two analyses, made by me with especial care in regard to this point, show conclusively that in this respect Röhrig's analyses are quite correct.

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[1] The Volcanoes of the Kula Basin, in Lydia, New York, 1894.

On the Basalts of Kula, Amer. Jour. Sci., Vol. XLVII, p. 114, 1894.

[2] ROSENBUSCH: Elemente der Gesteinslehre, p. 342, 1898.

It is uncertain whether Rosenbusch understood these rocks to be without any feldspar at all, or only without feldspar phenocrysts.

[3] RANSOME: Amer. Jour. Sci., Vol. V, p. 373, 1898.

As the rocks have been already described, it is not necessary to go into any lengthy account of their mineralogical features, and only the two analyzed will be mentioned.

The rock from a depth of 35 meters in a well digging in Kula is light gray, fine grained and slightly vesicular, with small phenocrysts of olivine and pyroxene visible. In thin section phenocrysts of pale gray pyroxene (diopside), olivine and of hornblende, which last in every case have been completely altered to a mixture of diopside and magnetite, are seen lying in a holocrystalline groundmass. This is composed of bytownite laths, small crystals and anhedra of diopside, magnetite grains and small apatites, with an ill defined, colorless mesostasis of low refractive index and small birefringence, which was previously referred to accessory orthoclase.

The tests made in Leipzig failed to reveal the presence of nepheline, but these have been lately repeated with care, and they prove beyond question that part of this interstitial, anistropic substance gelatinizes with acid and stains with fuchsine, while part of it remains unaffected. It is therefore established that nepheline is present in this rock, a conclusion in accordance with the results of analysis, as will be seen later.

A second specimen to be described is of a "leucite-kulaite," from the northeast flow of Kula Devit,[1] near the Gediz-chai,

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[1] This was spelled "devlit" in the former papers, following earlier authorities (Hamilton, Tschihatcheff) and as the word was apparently understood by the natives. It is really دويت "devit" an ink-stand, and not دولت "devlit" state or government. Cf. Inaug. Diss., p. 12.

Megascopically, this is similar to the other, but is darker gray and somewhat finer grained.

In thin section it shows fewer phenocrysts of diopside and olivine than the other, but more abundant, well-formed, hornblendes, which have all been altered, in some cases entirely, in others only partially, leaving some unchanged hornblende substance in the center. This alternation has not been as thorough as in the preceding, and, while here and there alteration to the usual diopside-magnetite aggregate is seen, in most cases the spaces formerly occupied by hornblende show a mass of the brown, pleochroic orthorhombic rods, which I have identified with hypersthene.

The groundmass is similar to the other, but flow structure is well marked. There are similar plagioclase laths (here andesine), also olivine and diopside crystals, generally stouter and better crystallized, and smaller grains of magnetite but scarcely any apatite. The most important difference is the presence in abundance of small round areas of a clear, colorless mineral, of low refractive index, and generally isotropic, containing inclusions of diopside needles and magnetite grains, arranged either centrally or zonally. While these round spots are mostly too small to show very marked abnormal double refraction, yet they occasionally do so, and there seems to be no doubt that they are to be referred to leucite. The mesostasis here is colorless and almost isotropic and glass-like, but it stains by treatment with HCl and fuchsine.

In the table are given the two analyses recently made by myself, as well as the corresponding ones of Röhrig. A few other analyses of similar rocks are inserted for comparison, and will be referred to subsequently.

It will be seen that Röhrig's analysis of the normal kulaite (II) agrees very well with mine (I) in all respects except in Fe_2O_3 and K_2O, which are respectively about 2 per cent. higher and lower. On the other hand, his of the leucite-kulaite (IV) resembles mine (III) only in MgO, CaO, and Al_2O_3, the TiO_2 present being weighed by him with the Al_2O_3. The other constituents differ rather widely.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
SiO_2	48.35	48.24	49.90	47.74	42.68	41.01	44.77	47.83	48.24	46.48	49.69
Al_2O_3	19.94	20.64	19.89	20.95	9.42	11.58	17.82	16.09	17.43	16.16	18.06
Fe_2O_3	2.48	4.63	2.55	3.29	11.55	12.54	5.05	4.32	7.22	6.17	2.64
FeO	5.25	5.55	4.78	6.32	7.23	7.60	6.95	3.62	1.17	6.09	6.19
MgO	5.15	5.02	5.05	5.16	10.09	8.67	8.22	5.53	3.99	4.02	5.73
CaO	7.98	7.94	7.21	7.56	13.15	12.20	10.36	10.68	6.09	7.35	8.24
Na_2O	5.47	5.08	5.60	7.12	2.71	2.57	2.13	4.46	4.28	5.85	2.99
K_2O	3.99	1.88	3.74	1.21	1.16	1.45	0.92	4.05	4.62	3.08	3.90
H_2O 110°+	0.22	0.02	0.19	0.04	1.06	1.87	2.64	0.24	2.78	4.27	0.91
H_2O 110°−	0.16		0.13					0.05			
CO_2	....	....	....	....	....	....	....	....	....	0.45	....
TiO_2	0.12	....	0.93	....	0.51	0.48	0.53	2.27	2.89	0.99	0.85
P_2O_5	0.84	0.97	trace	0.13	1.29	0.75	0.72	0.47	1.33	....	0.81
Cl	....	....	....	....	....	....	....	....	....	....	0.13
MnO	trace	....	trace	....	....	....	trace	0.38	trace	....	0.13
	99.95	99.97	99.97	99.52	100.85	100.72	100.11	99.56	100.47	100.91	100.27

I. Kulaite. Well digging. Kula. H. S. Washington anal.
II. Kulaite. Well digging. Kula. A. Röhrig anal. Am. Jour. Sci., Vol. XLVII, p. 122, 1894.
III. Leucite-kulaite. Near Gediz-chai, Kula. Washington anal.
IV. Leucite-kulaite. Near Gedis-chai, Kula. A. Röhrig anal. Loc. cit.
V. Hornblende-basalt. Todtenkopfchen, Rhone. Sommerlad anal. Neu. Jahr Beil, Band II, p. 155, 1883.
VI. Hornblende-basalt. Sparbrod, Rhone. Sommerlad anal. Loc. cit.
VII. Hornblende-basalt. Kosk Creek, California. Eakins anal. Diller. Amer. Geol., Vol. XIX, p. 255, 1897.
VIII. Leucite-tephrite. Falkenberg, near Tetschen, Bohemia. R. Pfohl anal. Hibsch. Min. Pet. Mitth. Vol. XIV, p. 105, 1894.
IX. Leucite-nepheline-tephrite. Niedermendig, Laacher See. R. Mitcherlich anal. Zeit. deutsch. geol. Ges., Vol. XV, p. 374, 1863.
X. Monchiquite. Cabo Frio, Brazil. M. Hunter anal. Hunter and Rosenbusch. Min. Pet. Mitth., Vol. XI, p. 454, 1890.
XI. "Basalt." Table Mountain, Denver, Colorado. Eakins anal. Cross. Mon., XXVII U. S. Geol. Surv., p. 308, 1896.

As the original specimens were small, these differences cannot be ascribed to differences of composition in different parts of the mass, but are more probably due to the different analytical methods used. This applies especially to the alkalis, in the determination of which the usual German method of treatment of the rock with HF and $H_2 SO_4$, and subsequent separation of Al, Fe, Mg, and Ca, instead of the much more expeditious and accurate method of J. Lawrence Smith, tends to erroneous and discrepant results largely through contamination with alkalis derived from the glass vessels and reagents employed.

Having thus obtained an insight into the chemical and mineralogical composition of these rocks, it will be well to determine their place in the present scheme of classification.

In the first place, the very close correspondence of both my analyses, except in the minor constituents TiO_2 and P_2O_5, show that, in any scheme based on this character alone, they are to be classed together. Indeed, this is true of all the rocks of the Kula region examined by me, as shown by the analyses of Röhrig given in the original paper.

From a purely chemical standpoint it is abundantly evident that they are not to be referred to the basalts as this name is at present understood, since the alkalis are far too high for this group of rocks. The alumina is also too high, at least in comparison with the basalt analyses in which this constituent has been determined with proper care. Nor are they to be put with the subgroup of hornblende-basalts, as is shown by comparison with some typical analyses of these given in V, VI, and VII. The Kula rocks differ from these in having higher SiO_2, Al_2O_3 and alkalis, and lower iron oxides, MgO and CaO. In other words, they are more properly leucocratic, while the hornblende-basalts are melanocratic. At the same time the hornblende-basalt from Kosk Creek (VII), described by Diller, occupies a rather intermediate position between the Kula rocks and the typical hornblende-basalts of the Rhone and other regions.

The closest analogues of the Kula rocks are to be found among the nepheline-tephrites and nepheline-basanites. It is true that many of these are markedly lower in SiO_2, Al_2O_3 and Na_2O, but at the same time analyses of these are to be found which closely resemble mine of the Kula rocks, as those of the nepheline-tephrite from the Falkenberg, near Tetschen, Bohemia, described by Hibsch (VIII), and the leucite-nepheline-tephrite of Niedermendig (IX).

They also resemble closely the monchiquites, as shown by a typical analysis of one of these (X), the main difference being in the higher content of H_2O in the monchiquites, consequent on their containing analcite in place of nepheline.[1]

Rocks which chemically closely resemble these are certain "basalts" from Colorado, described by Cross, an analysis of one of which is given in XI. These carry considerable orthoclase, but no nepheline, and with biotite instead of hornblende.

Turning to the mineralogical composition, it must be noted that most of the Kula rocks present a peculiarity which adds somewhat to the difficulty of classification. They have been spoken of as containing hornblende as an essential constituent. This is strictly true only of the more glassy varieties, in which basaltic hornblende is fresh and unaltered. In the others—including those analyzed—this mineral has been partially or entirely altered to hypersthene, diopside and magnetite, so that, speaking with strict accuracy as to their present composition the majority of them cannot be said to contain any hornblende at all.

This naturally raises the difficult question, whether the original hornblende should be recognized as a component. Of its initial presence, and the derivation of the hypersthenic and diopside-magnetite "mixed crystals" or pseudomorphs from it there can be absolutely no doubt, from the evidence of the shape of the pseudomorphs, the transitions to unaltered hornblende, and other facts observed here and elsewhere.

The case is strictly comparable with the occurrence of so-called "pseudo-leucites," mixtures of orthoclase and nepheline or muscovite, pseudomorphous after original leucite. As rocks containing these are called "leucite-syenite," "leucite-eleolite-syenite" and "leucite-phonolite" by Rosenbusch and Zirkel, it would seem to be justifiable, at least for the present, to speak of the Kula rocks as hornblende-bearing.

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[1] Cf. L. V. PIRSSON: JOUR. GEOL., Vol. IV, p. 679, 1896.

The analyses I and III calculate out very sharply as shown in the table below, with results worth commenting on. In the first place this calculation confirms the observation that nepheline is present, as there is too much Na_2O or too little SiO_2 to satisfy each other on any other basis.

	I a	III a[1]
Anorthite	17.9	17.9
Albite	8.4	23.6
Orthoclase	23.4	..
Leucite	..	17.4
Nepheline	20.4	12.8
Diopside	12.8	13.8
Olivine	10.7	9.5
Magnetite	3.7	3.7
Apatite	1.8	..
Water, etc.	0.8	1.3
	99.9	100.0

It is also of interest to note that, although these rocks are so basic in composition, and so basaltic in general habit and appearance, yet the feldspars and feldspathoids constitute over 70 per cent. of the mass, and that they consequently are leucocratic, to use the distinction into two groups recently given by Brögger.[2] So little is known of the rocks of Asia Minor that as yet no melanocratic complements of these are positively known, though it is to be expected that they will be discovered some time in this petrographic province.

It will be noticed that in I the plagioclase is a bytownite of the composition Ab An_4, while in II it is an andesine, approximately Ab_3 An_2. It is certainly remarkable that in the one rock orthoclase is associated with the lower SiO_2, as well as with a bytownite, while in the other leucite occurs with higher SiO_2 and lower K_2O, and with the plagioclase an andesine. In the latter also the albite molecule is higher and nepheline correspondingly lower, while the other constituents (except apatite) remain the same.

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[1] Inasmuch as diopside, hornblende, hypersthene and olivine are present together in III, it is impossible to calculate the exact relative amounts of each, and the analysis has, therefore, been calculated on the assumption that only diopside and olivine are present. The error involved will not be large, as the hornblende tends to alter to a mixture of diopside and magnetite.

[2] BRÖGGER: Erupt. gest. d. Kristianiageb, III, p. 263, 1898.

This is peculiar, but there seems to be no doubt of the facts, and the difference is possibly to be connected with differences in the conditions of solidification. The specimen of I came from a depth of thirty-five meters in a lava flow, possibly of Kula Devit, but more probably of an earlier volcano, while the leucite-kulaite was from the surface of a late flow of Kula Devit.

There would thus have been certain, even if slight, differences in pressure and rate of cooling, which might account for the difference in mineralogical composition. It has already been pointed out elsewhere[1] that these intermediate latitic magmas seem to be in a nicely balanced state of chemical equilibrium which only need very slight differences in conditions of solidification to result in quite diverse mineralogical aggregates. The facts here are also in accordance with the general observation that leucite is essentially a mineral of the effusive rocks, while orthoclase occurs in either intrusive or effusive masses, this tendency toward the formation of leucite in flows in contradistinction to the formation of orthoclase in domal eruptions being especially well seen along the main line of Italian volcanoes.[2]

We have already seen that the analyses correspond most nearly with those of the tephrites. Accepting, however, the general definition of a tephrite as an effusive rock composed essentially of plagioclase and nepheline or leucite, with pyroxene or other ferromagnesian components, it is very clear that the rock represented by analysis I, which contains 23 per cent. of orthoclase, cannot properly be put in this group. Indeed, the calculated mineral composition, yielding 23.4 per cent. of orthoclase and 26.3 of plagioclase, is fully corroborative of the position to which Rosenbusch assigns this rock, among the latites or trachydolerites.

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[1] H. S. WASHINGTON: JOUR. GEOL, Vol. V, p. 376, 1897.
F. L. RANSOME: Amer. Jour. Sci., Vol. V, p. 370, 1898.

[2] Cf. JOUR. GEOL., Vol. V, p. 376, 1897.

It would seem, then, advisable, as well as justifiable, to reserve the name "kulaite" to denote a basic rock of the series of latites (Rosenbusch's trachydolerites), in which orthoclase and lime-soda feldspar are present in about equal amounts, together making up half the rock, with nepheline to the extent of from 12.5 to 25 per cent. The ferromagnesian constituent is typically hornblende or pseudo-hornblende, and diopside and olivine are also present. These rocks, though low in silica, are essentially leucocratic in character.

The case of the "leucite-kulaites" is rather different. On the basis of chemical composition and genetic association they would naturally be classed with the kulaites, as varieties of these in which leucite replaces orthoclase. At the same time, composed as they are of plagioclase, nepheline and leucite, with ferromagnesian minerals, they are perfectly covered by the tephrites, and in the present schemes must be called leucite-nepheline tephrite.

I have gone at some length into the question of the position and names of these rocks, not because the matter is of any great importance in itself, but because they serve very well to exemplify the difficulties and complexities of our present methods of classification. It is the old story of magmas of identical chemical compositions solidifying as different mineral aggregates. With the rapid increase in our knowledge of rocks, and especially through more numerous analyses and their more careful execution, examples of this are becoming of quite frequent occurrence in petrographical literature. Most cases, as those of venanzite and madupite, the minette or selagite of Monte Catini and wyomingite, and many more, are of rocks from widely distant parts of the globe.

Here, however, there are found at one small center recent flows which must be referred to the distinct groups of basic latites, leucite-tephrites and, to include the tachylitic varieties described in the original papers, hornblende-limburgites. These rocks which, according to the principles of classification at present in vogue, we must place in such diverse and distant parts of our scheme, are all products of one center of eruption, parts of the same undifferentiated magma, identical in chemical, and in many points of mineralogical, composition. A rational or natural scheme of classification should express their evident close relationship, but on account of somewhat diverse mineralogical composition, due to such extraneous and accidental causes as conditions of cooling and the like, their mutual affinities are to a large extent masked by the diverse names which must be given them.

We are brought face to face with the question, whether we should hold to the present system, based on structure and (largely qualitative) mineral composition; or whether we should strive to base our classification primarily on the most fundamental character of igneous rocks—their chemical composition, the quantitative mineral composition being a function and an exponent of this.

The choice of the latter would certainly seem to be justified on sound theoretical grounds, and has been advocated by Pirsson,[1] Iddings,[2] Brögger,[3] Loewinson-Lessing,[4] and others. It is, of course, also well known that Brögger holds that genetic relationships should find expression in classification; in other words, that the system of classification should be not a Linnean but a natural one. But discussion of this and kindred topics would carry us far beyond the limits of this paper.

That any change will present difficulties of a practical as well as of a theoretical nature is obvious. The aid of chemical analysis, as well as of the microscope, must be invoked much more often than in the past, though with increasing knowledge this would be less vital in many cases than may be thought by some. Cases of uncertainty as to the position and relationships of a particular rock will occur, but presumably less frequently than under the present system. These and other difficulties will have to be met and overcome. But, as Iddings, Brögger, and others have urged, the time is at hand for a revision and change of our whole system of classification and subsequently of nomenclature, and it is well to remember the general truth of the saying, "*C'est le premier pas qui coûte.*"

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[1] PIRSSON, Amer. Jour. Sci., Vol. L, p. 478, 1895.

[2] IDDINGS, JOUR. GEOL., Vol. VI, p. 103, 1898.

[3] BRÖGGER, Amer. Jour. Sci., Vol. IX, p. 458, 1900.

[4] LOEWINSON-LESSING, Compt. Rend., VII, Cong. Geol. Int., 1897, pp. 193–464.

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